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# ENGINEERING REPORT

SECURITY INFORMATION

**REPORT NO:** 195-A **DATE.** 2-1-53

**TITLE:** PULSE-JET HELICOPTER POWER CONTROL SYSTEM DEVELOPMENT

FIRST QUARTERLY PROGRESS REPORT

**MODEL NO.** **COPY NO.** 52

**CONTRACT NO.** AF 33(600)-5860 Supplement No. 4 Items 1(d) and 1(e)

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1. SUMMARY

A tentative specification for a pulse-jet helicopter power control system has been established and several basic systems have been examined in the light of this specification.

The most promising configuration involves a programming linkage between the collective pitch control and the throttle, with the possible addition of a simple governor as a trimming device if the simple linkage leaves undesirably large residual errors.

Helicopter and pulse-jet performance data are being prepared so that detailed studies of promising configurations may be undertaken.

A flow bench for testing fuel system components is being fabricated.

## 2. INTRODUCTION

This is the first quarterly progress report describing work performed under Items 1(d) and 1(e) of U. S. Air Force Contract No. AF 33(600)-5860 Supplement No. 4. These items cover the development of a basic power control system for pulse-jet powered helicopters and the investigation of cyclic fuel injection as a means of reducing in-plane vibration and torque variation.

# 3. PRELIMINARY CONTROL SPECIFICATION

## 3.1 INTRODUCTORY COMMENTS

This specification sets forth the characteristics desired in a power control system for pulse-jet powered helicopters. Revisions will be made from time to time during the course of investigations performed under the present contract with the goal of defining an optimum control system considering performance, weight, reliability, and other parameters.

## 3.2 CONTROLS PERFORMANCE REQUIREMENTS

### 3.2.1 Generalized Performance Requirement

The control shall relieve the pilot of the task of coordinating engine fuel flow with changes in power required. Ideally, the control will correct for all changes in flight path, gross weight, altitude, etc., without adjustment by the pilot. If necessary, a compromise system will be considered wherein the pilot may be called upon to perform "trimming" adjustments; however, any such adjustments must be small enough that they will require only occasional attention on the part of the pilot.

### 3.2.2 Engine Fuel Flow

The control system must maintain engine fuel flow between the lean and rich blow-out limits at all altitudes within the design operating range of the helicopter. At the same time, it should permit attainment of maximum thrust and throttling ranges. On the basis of the operating characteristics of current pulse-jet engines, tolerance bands of ±10% can be established for both maximum and minimum specified fuel flows with out risking blowout and without significant reduction in maximum thrust or throttling ranges.

### 3.2.3 Rotor Speed Regulation

Steady state regulation of the rotor rpm shall be maintained within ±5% of the specified value for all operating conditions of the helicopter.

During abrupt maneuvers, transient variations of rpm as great as +10% and -20% will be tolerated provided that no excursion beyond the ±5% band persists for longer than three seconds.

### 3.2.4 Response Rate

The response rate of the control system shall be sufficient to enable the pilot to reach zero sinking speed following a minimum-power autorotational descent within a period of one second after the initial corrective action. It is believed that if this requirement can be met, the response rate will be adequate for all other flight maneuvers.

3.2.5 Stability and Damping

The system shall be both statically and dynamically stable and shall be damped to the maximum extent compatible with the response rate requirement.

3.2.6 Checkout Provisions

The control system shall be designed so that its proper operation can be assured during ground operation before take-off.

3.3 CONTROL PHYSICAL REQUIREMENTS

For purposes of weight and power specification, the control system shall be defined as consisting of all components over and above those required by a single manually controlled fuel and collective pitch system.

3.3.1 Control System Weight

The control system weight shall not exceed 1/2% of the maximum hourly fuel consumption of the helicopter for which it is designed.

3.3.2 Control Power Requirement

The control system shall not require more than 1% of the maximum helicopter rotor horsepower. The control shall not rely on the helicopter system for hydraulic or electrical power.

3.4 MISCELLANEOUS REQUIREMENTS

3.4.1 Environmental Conditions

The control system shall be capable of satisfactory operation over the entire atmospheric and operational range specified for the helicopter for which it is designed.

3.4.2 Storage and Handling

The control system shall be designed and constructed so that it may be stored, shipped, and placed in operation with the same freedom from maintenance and adjustment which characterizes pulse-jet helicopters.

3.4.3 Maintenance

Field maintenance procedures shall be simple and shall not require special tools or test instruments.

3.4.4 Fuels

The power control system shall be designed to operate with aromatic fuel as defined in Specification AN-F-42.

## 4. POSSIBLE CONTROL SYSTEMS

Pulse-jet helicopter power control systems may be classified under three broad headings as follows:

(1) Governed Throttle

a. Proportional Governors
b. Reset Proportional Governors
c. Isochronous Governors

(2) Governed Collective Pitch

a. Proportional Governors
b. Reset Proportional Governors
c. Isochronous Governors

(3) Programmed Throttle

a. Untrimmed
b. Pilot Trimmed
c. Governor Trimmed

### 4.1 GOVERNED THROTTLE

This form of power control parallels closely the governor system which has been applied successfully to a wide variety of stationary power plants as well as to farm tractors and other vehicles. As applied to a helicopter, this system offers reasonably accurate rotor speed control without limiting the pilot's control of collective pitch. During take-off, landings, hovering, and other precise maneuvers essential to helicopter operation, the pilot must be able to utilize the kinetic energy of the rotor system to effect rapid changes in flight path even through such control applications may cause the rotor power required to fall beyond the capabilities of the power plants, (with resultant transient changes in rotor rpm).

A well designed throttle-governed system incorporating rich and lean limit stops can be expected to maintain reasonably constant rotor rpm during all maneuvers wherein the rotor power required remains within the power plant capabilities and to maintain fuel flow within the engine operating limits throughout all flight maneuvers. The pilot will be required to monitor the rotor speed during rapid maneuvers which rely on rotor kinetic energy for their successful completion.

The choice of governor type for this system would be based upon their relative simplicity and adequecy. The simplest and most reliable unit giving adequate stability and accuracy would naturally be selected.

4.2 GOVERNED COLLECTIVE PITCH

At first glance, this system appears analogous to the conventional pitch governing system used for speed control of conventional piston engine-propeller combinations. Actually, however, the insignificant amount of kinetic energy stored in the engine-propeller combination would be of no value to the pilot even if he had direct control of propeller pitch; whereas, the kinetic energy of the rotor system is an essential portion of the maneuvering ability of a helicopter. A more valid analogy between helicopter and airplane control would be to compare helicopter collective pitch with airplane angle of attack and to consider helicopter fuel flow analogous to airplane fuel flow at a given propeller rpm. In this analogy the angular kinetic energy of the helicopter rotor system is represented by the forward flight kinetic energy of the airplane. Airplane piloting experience has shown that the best method of maintaining constant airspeed and vertical speed is to use the elevators to hold constant airspeed and to use the throttle to hold the required rate of climb or descent. If a governor were to be installed in an airplane to maintain absolutely constant airspeed, the only possible arrangement would be to allow the pilot to actuate the throttle and to give the governor full control of the elevators. The resulting system would be entirely adequate for cruise operation and for gradual climbs and descents; however, it would have to be over ridden for take-offs, landings, acrobatic maneuvers, and any other flight conditions where forward flight kinetic energy must be under the pilots direct control. In short, a constant speed governing system which deprives the pilot of direct pitch control would be useable except during the very maneuvers where dangerous speed changes are likely to occur.

The conclusions of the above analogy may be applied directly to the helicopter power control system. A governed-pitch system would provide extremely accurate rotor speed control during mild maneuvers, but would have to be over ridden during the more active maneuvers where dangerous overspeed or underspeed are most likely to occur. This system offers little, if any, advantage over the governed-throttle system, and it has the serious failing of requiring an overriding control of collective pitch. Moreover, since the primary control action of the governor system would be concerned only with collective pitch, an additional control would be necessary to limit engine fuel flow to values within the operating range. It is, therefore, concluded that the governed-pitch power control system does not warrant additional consideration for pulse-jet helicopter application.

4.3 PROGRAMMED THROTTLE

The programmed throttle type power control system is widely used on current reciprocating-engine-powered helicopters. It could conceivably incorporate correcting elements to compensate for forward speed, altitude, and other variables so that the exact throttle setting required for a given flight condition would be obtained automatically - subject

of course, to rich and lean-limit stops which would also be provided. In most reciprocating engine helicopters, no such compensating elements are included; and the pilot is left with a monitoring and trimming function to perform. Since even the most complex governor system considered in the foregoing paragraphs was inadequate to relieve the pilot of rotor speed monitoring responsibility during exacting maneuvers such as hovering and landing, it seems quite reasonable to consider this extremely simple system which adds to his responsibility only during gentle maneuvers where infrequent checks of rotor speed will be sufficient and where his constant attention is not demanded outside the helicopter.

The programmed throttle control system is therefore recommended for more detailed study. First preference should be given to the simplest form of linkage between throttle and collective pitch, with compensating elements and/or governor trimming being considered only if residual errors in the simple system appear to require excessive pilot attention.

The programmed throttle control system with a proportional governor used for trimming out residual errors is essentially the same system listed earlier as a reset proportional governor throttle control. Since it may become necessary to incorporate some form of governor into the contol system regardless of the initial approach to the problem, it is recommended that various governor manufacturers be canvassed to obtain data on existing governors which might be applicable.

## 5. FUEL SUPPLY SYSTEMS

Regardless of the power control system adopted, the means used for providing adequate pressure at the pulse-jet fuel injection nozzle is an important part of the overall fuel (and, hence, power control) system. The fuel systems used by this Contractor to date have all employed rotor pumping to provide the high fuel pressures essential for efficient fuel injection. A fuel pump is used only to force the fuel through the throttles, flow meters, and rotary seals into the rotor proper. With this system, the fuel column in the line at the rotor tip adjusts its length automatically to maintain the engine fuel flow equal to the throttle fuel flow; unfortunately, however, there is a time lag associated with this process which may become intolerable under certain transient operating conditions. It is possible to incorporate design features which will minimize or obviate this lag at the expense of small increases in system complexity. The primary advantages of the rotor pumping system are its simplicity (even with the additions just mentioned) its reliability, and its inherent regulation (overspeed of the rotor has only a momentary tendency to produce increased engine fuel flow).

The alternative to a rotor pumping fuel system is one incorporating a balancing valve at the rotor tip which automatically cancels the pressure rise due to centrifugal action and delivers fuel to the engine at the pressure established by the pump-throttle combination. The automatic balancing valve is demanding of design ingenuity and manufacturing accuracy and it may represent a maintenance and reliability handicap; it must be stated, however, that such valves have been successfully operated on several experimental jet propelled helicopter rotors. A second fundamental disadvantage of this system is the added load which it places on the helicopter fuel pump. The added pump horse power is directly chargeable to the control system as is any added accessory drive system weight required to transmit the power to the fuel pump. Fuel pumps designed for high pressure output are not available in a wide range of flow capacities, so the system may be further penalized by the use of an oversized fuel pump.

The pressure-cancelled rotor fuel system has two primary advantages, (a) minimum time lag and (b) excellent regulation (overspeed has no tendency to produce increased fuel flow). However, many modified systems intended to minimize the fuel pump problem result in very poor regulation, and this factor must be kept in mind in evaluating systems of the "partial cancellation" type.

No attempt will be made to choose between rotor-pumping and pressure-cancelled systems at this time. However, the limitations of the two systems will be considered during the control-system-evaluation studies which will be conducted during the next few months.

## 6. HELICOPTER AND PULSE-JET PERFORMANCE DATA

In order to evaluate the possible performance of the various power control systems previously mentioned, it will be necessary to have representative data regarding helicopter aerodynamics and pulse-jet engine performance. Since the XH-26 is the only AF "Handbook" type pulse-jet helicopter which will be available for flight testing of the power control system during the life of the present contract, it appears logical to design the control around the specific requirements of the XH-26. Every effort will be made, however, to maintain the control system studies on as general a basis as is possible so that the results will be applicable to other pulse-jet helicopters with a minimum of extrapolation. In accord with this policy, XH-26 aerodynamic data are being reduced to a dimensionless form for use in evaluating proposed power control systems.

The performance of this Contractor's current AJ-7.5 series engines will be assumed to be typical of rotor-tip mounted pulse-jet engines for purposes of this study.

## 7. FUEL FLOW BENCH

A flow bench for testing fuel system components has been designed and is in the process of fabrication. It is anticipated that this bench will be of considerable value in proving out various components of the fuel system such as pumps, valves, accumulators, etc Moreover, it will be an absolute necessity in developing programming cams and/or governor arrangements in connection with the power control program. A schematic diagram of the flow bench is included as Fig. 1 of this report.

## 8. CYCLIC FUEL INJECTION

Initiation of design and analytical studies of cyclic fuel injection have been postponed to a somewhat later period pending the establishment of the basic power-control system. Since the cyclic control components must be integrated with the power control components, their design is very much affected by the type of system adopted.

Pilot reports regarding XH-26 flight characteristics indicate that rotor in-plane vibration is either missing entirely or is extremely weak. Analytical studies of the cyclic fuel injection problem will, however be undertaken at the earliest opportunity.

## 9. CONCLUSIONS

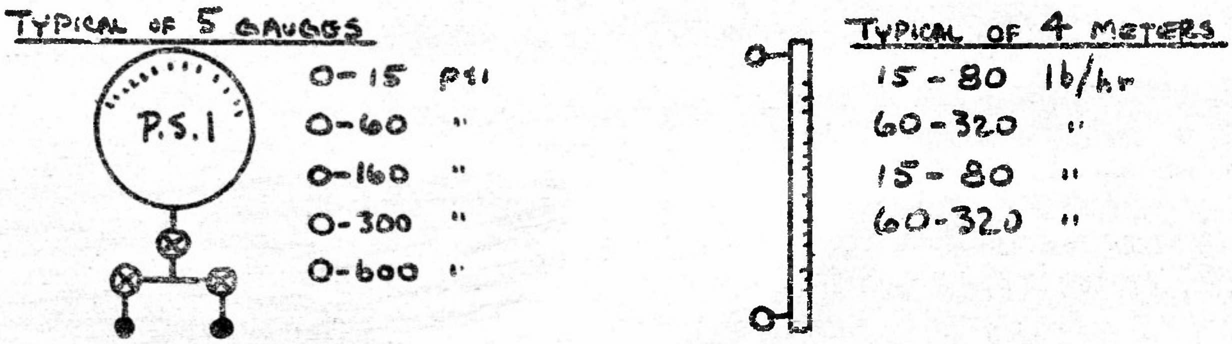
It is concluded that the fundamental worth of a pulse-jet helicopter power-control system lies in its effectiveness in allowing the pilot to obtain the maximum maneuverability from the helicopter with the minumum effort on his own part. Merely specifying the maintenace of constant rotor rpm does not necessarily specify the best overall power control system; in fact, certain transient variations of rotor speed are necessary during normal helicopter maneuvers.

Some form of programmed throttle actuation with collective pitch change, (with the possible inclusion of a simple governor as a trimmer) appears to be the most promising configuration.

Since the controls developed under the present contract will be flight tested initially on the XH-26 Helicopter, the use of XH-26 aerodynamic and power plant data is indicated for the present study. Wherever possible, of course, the study will be generalized to apply to all pulse-jet powered helicopters.

# FLOW BENCH SCHEMATIC DIAGRAM

O ~ TAPS ON FRONT PANEL ONLY.
● ~ TAPS ON BOTH FRONT & BACK PANELS.



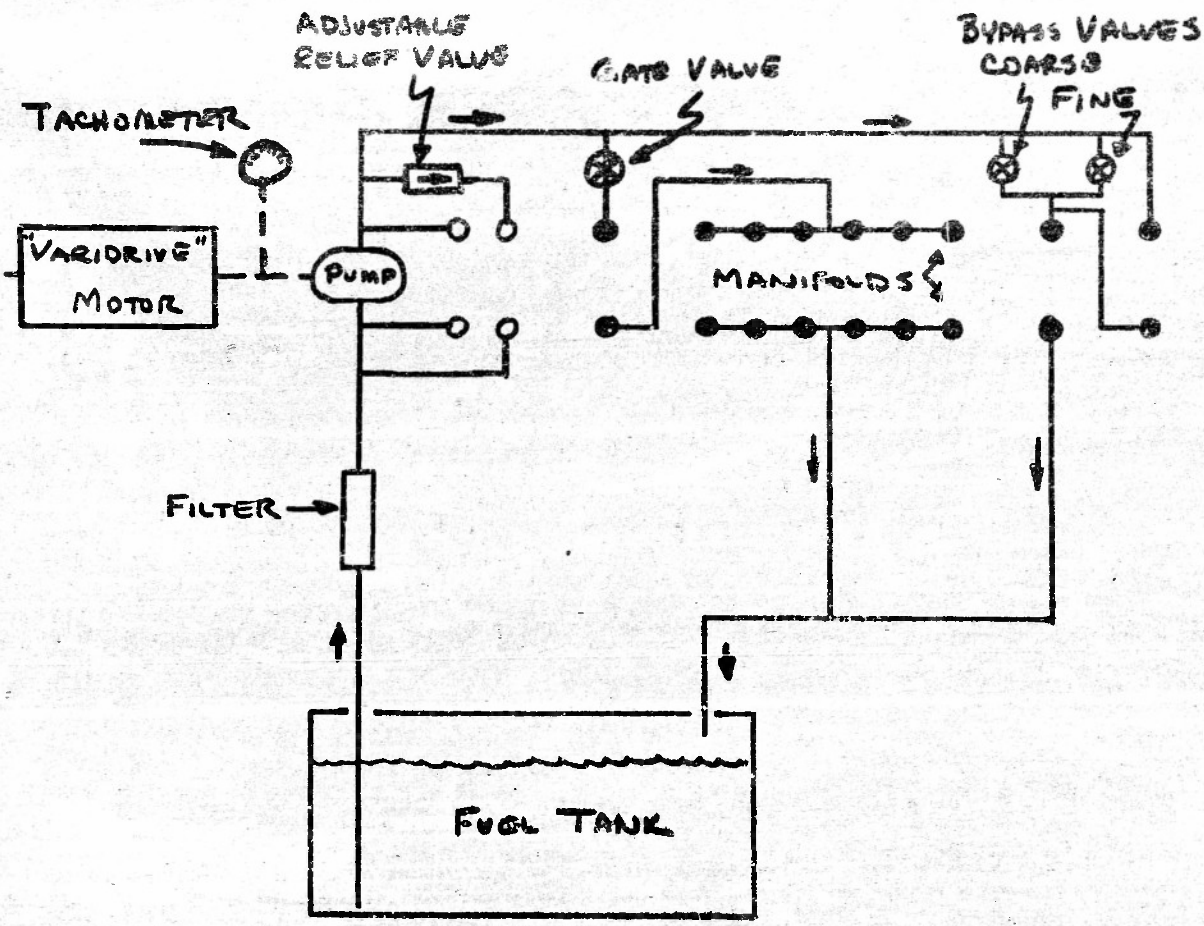




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FIGURE 1